U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TREC TECHNICAL REPORT 61-41

ACHIEVING CONSISTENCY IN MAXIMUM PERFORMANCE STOL LANDINGS

Project 9R38-11-009-02

Contract DA 44-177-TC-356

January 1961

prepared by :

THE UNIVERSITY OF WICHITA
Wichita, Kansas

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ACHIEVING CONSISTENCY IN MAXIMUM PERFORMANCE STOL LANDINGS

By

A. J. Craig

TREC Technical Report 61-41
UWER Report No. 351

Performed for
U.S. Army Transportation Research Command
Transportation Corps
Fort Eustis, Virginia
under
Project 9R38-11-009-02
Contract DA 44-177-TC-356
Job Order No. 6

January 1961
University of Wichita
Department of Engineering Research
Wichita, Kansas

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SYMBOLS

C_L	airplane lift coefficient, $\frac{\text{LIFT}}{\rho/2SV^2}$
L	field length, ft
M	computed minimum landing distance, ft
R	radius of flare, ft
X_a	average excess landing distance, ft
X_w	greatest excess landing distance, ft
γ	flight path angle, degrees or radian as noted
V	velocity, ft/sec
ρ	air density, slugs/cu ft
S	wing area, sq ft

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SUMMARY

Factors influencing the achievement of minimum distance landings over a barrier were investigated to determine what might be done to provide consistency in landing in a computed minimum distance. It was found that the pilot regularly extracted the maximum aerodynamic performance of the airplane, but that limitations accompanying maximum aerodynamic performance prevented consistently short landings. The primary limitation was the inability to flatten or steepen the descent path during the approach to the barrier.

INTRODUCTION

Maximum landing performance of an airplane is defined to be the minimum landing distance, arbitrarily taken from a 50 foot obstacle. This minimum distance is usually a computed value based on the aerodynamic parameters of an airplane and ignores the consistency with which a pilot can achieve it. The field length from which an airplane can operate, however, exceeds the minimum landing distance by a margin sufficient to accommodate the worst tolerable performance of the pilot-airplane combination. When this tolerance is exceeded either a go-around must be executed or an accident will result.

Many previous investigations have been conducted to determine the aerodynamic parameters of various airplanes, two of which were conducted at the University of Wichita (Ref. 1 and 2). At some time or another every operational airplane is so tested and a computed landing distance is therefore available for each. Only a few studies have been made, however, of the consistency with which a pilot can achieve the best performance.

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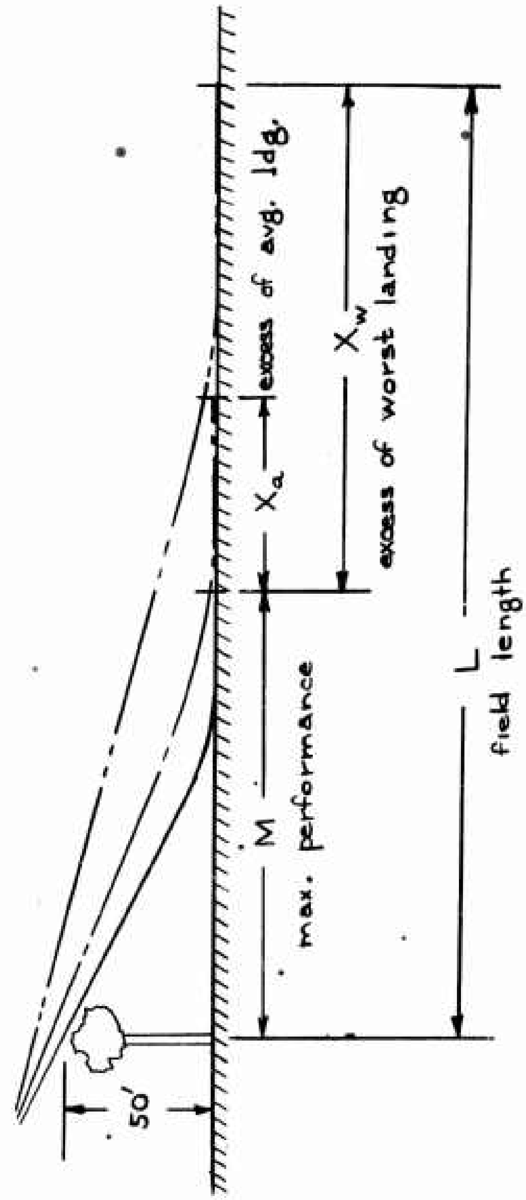

Figure 1.

In Fig. 1, X_w represents the excess distance above the computed landing distance, M, which results from the inability of the pilot to consistently fly the airplane at maximum performance conditions. As M is decreased for STOL aircraft, the excess distance X_w will become a larger proportion of the total landing distance unless it is reduced also. The merit of continuing to improve airplane performance is questionable if X_w is of the same order as M, and an investigation was therefore proposed to study the magnitude of X_w relative to M on a contemporary aircraft, to determine the factors that influenced X_w and M, and finally to determine if any method existed by which X_w could be reduced.

FACTORS INFLUENCING TOTAL LANDING DISTANCE

Presuming a given airplane is involved, the aerodynamic parameters of which are held unchanged, the factors that influence X_w or the accuracy of landing at the minimum distance point would appear to be:

1. Factors in the approach
    a. Approach to the barrier - Techniques by which the pilot may guide the airplane to the barrier include a power-off steady-state descent; a power-on, level, slow-flight approach; and intermediate combinations of the two.
    b. Height at the barrier
    c. Lift coefficient at the barrier
    d. Path angle at the barrier
2. Factors in the flare maneuver
    a. Height at which the flare is commenced
    b. Elevator action in the flare
    c. Ground effects
    d. Pitch attitude at touchdown
3. Factors in the ground roll

The effect of these factors was sought from data obtained on a DeHavilland Otter U-1A aircraft in a previous program (Ref. 2).

From these data, the type of landing procedure which had produced the best results was determined, and the group of landings using this technique were analyzed. However, the detail of measurement in these data was insufficient to provide an accurate description of the landing maneuver, particuarly during the transient motion of a flare. The same airplane was therefore fitted with revised instrumentation and another group of landings were performed using the selected technique. In addition, a mathematical model of the airplane was constructed on a digital and on an analog computer. The latter group of flight test data and the computer results were then analyzed for the effects of the factors listed above on landing performance.

ANALYSIS OF THE FACTORS

In the flight tests performed for this program, erratic mechanical performance of the brakes on the test aircraft made it difficult to maintain directional control during deceleration. This resulted in a ground roll which varied from 270 to 760 feet, and this variation is of the order of the air distance of a typical landing. Thus poor or inconsistent braking action can lengthen a landing by 50% of the minimum value.

It was felt that more representative ground roll distances were obtained in a previous program on this airplane, where the ground roll varied from 250 to 445 feet. Of this group of landings, the shortest ground roll, 250 feet, resulted in excessive wear on the tires and was not considered to be typical of operational practices, while the longest ground roll, 445 feet, occurred only once in ten landings. An average value of 400 feet for the ground roll of a U-1A aircraft with properly functioning brakes was found to be both repeatable and safe with regard to tire failure, and this value was added to air distances measured in the current test program as well as the computed minimum air distance to obtain a total landing distance figure. (See P.11).

1. Factors in approach

   a. Effect of pilot technique in approaching the barrier - Consistently short landings could be made using a completely power-off technique only in calm wind conditions and after several practice runs to establish a ground reference point out on the approach path. That this should be the case is shown in Fig. 2. The plot presents the range of static equilibrium path angles available at various combinations of flap deflection and angle of attack in the power-off condition. The significant feature is the nearly constant value of path angle which results for any lift coefficient at landing flap deflection. When the pilot closed the throttle and established a trimmed condition for a power-off approach, the path angle was necessarily within 1/2 degree of 7.5 degrees. As the landing proceeded, if the pilot sensed that a projection of the path he was on would not pass sufficiently close to the barrier, there was little he could do either to steepen or to flatten the path.

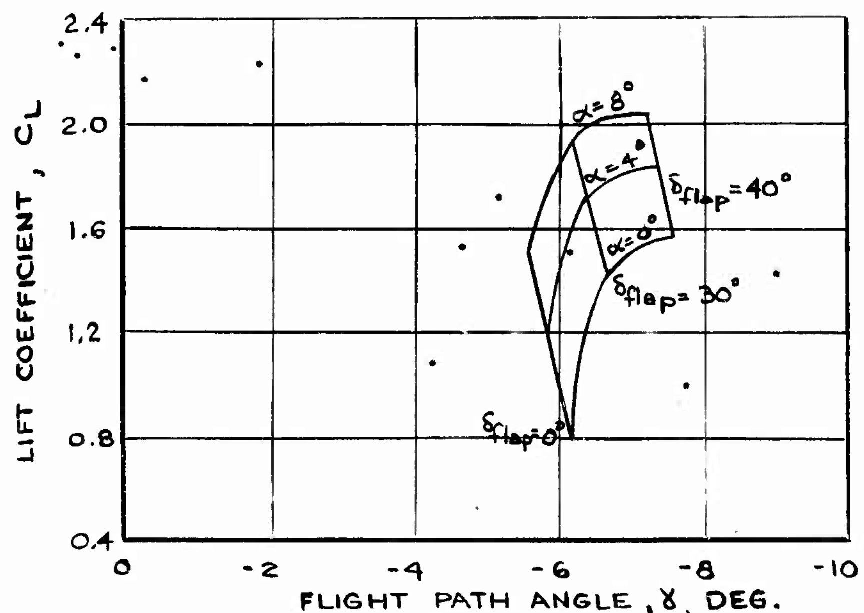

Figure 2

Use of power-on, slow-flight technique provided the desired plus-minus path correction capability but the average path was more shallow due to holding power on, and this lengthened the total landing distance. Furthermore, with this method the pilot must compensate for the lag in transient response of path angle to throttle in anticipating path errors. For the U-1A this transient response was characterized by a first-order time constant of almost three seconds.

The most successful technique involved a combination of the two procedures. A deliberate undershoot at constant airspeed to the steepest (power-off) path to the barrier was used with periodic application of throttle to keep the undershoot small, hence quickly correctable. In all cases, the pilot tried to pass the barrier in a steady-state, power-off descent. The success of this technique is shown in Fig. 3 where it can be seen that in 90% of the landings the path angle deviation from -7-1/2° was within ±1°. Those points showing a

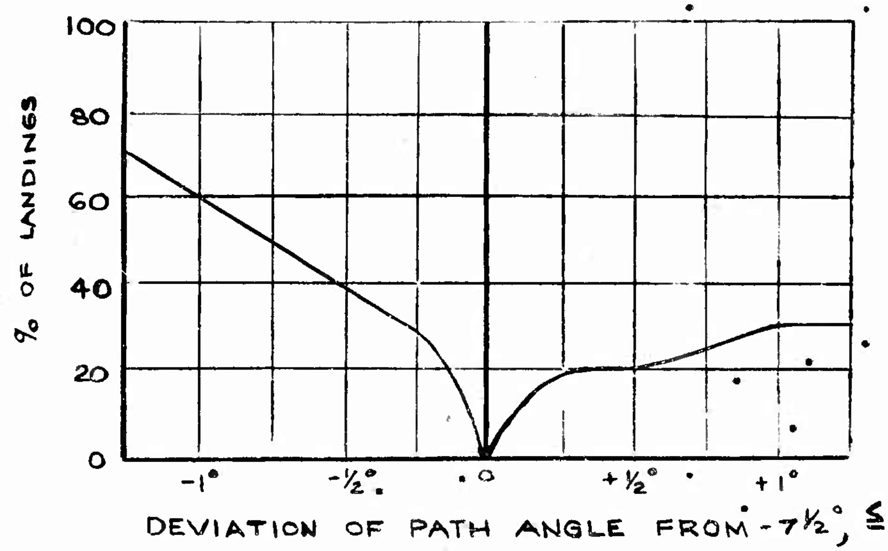

Figure 3

path angle steeper than that possible in Fig. 2 were non-equilibrium cases where the pilot dived the airplane in passing the barrier.

b. Effect of height at the barrier - Of all factors measured, the altitude above the barrier appeared to be the most significant. Fig. 4 shows a near-linear relationship of approximately 1:10 between excess height at the barrier and extension of landing distance. The plot does not demonstrate a true partial derivative since variables other than height at the barrier (such as C_L and γ) were not held constant. Fig. 4, therefore, includes the gross effect of height, C_L, and γ at the barrier upon air distance from the barrier to touchdown.

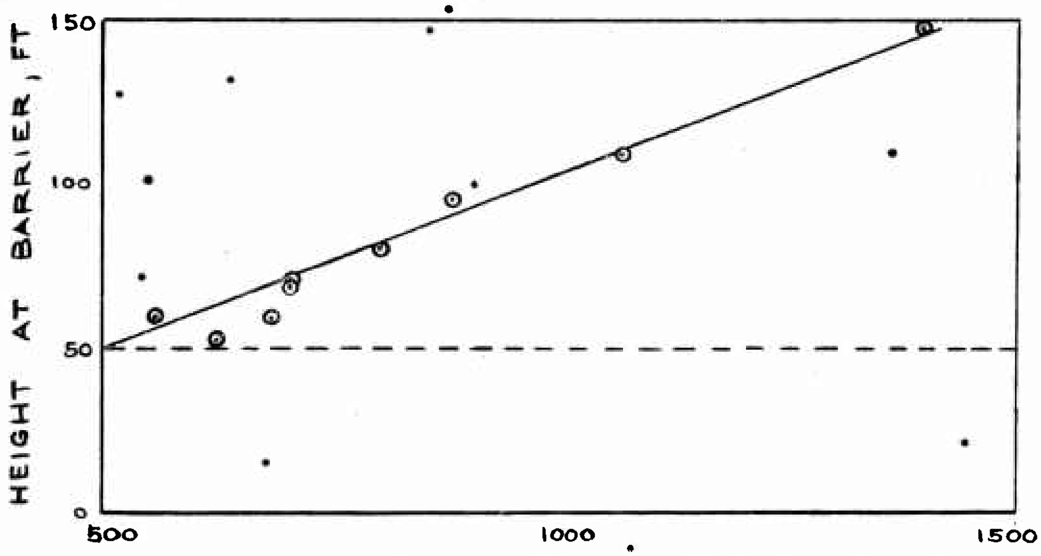

Figure 4

The effect of height at the barrier can be removed from the data by considering air distance to be measured from the point at which airplane height was 55 feet to the point of touchdown, and plotting C_L and γ versus this distance. When this is done, the resulting plots (Figs. 5 and 6), show the total variation in air distance with either variable to be small in comparison to the combined effect seen in Fig. 4. Landing consistently at the minimum distance point, therefore, depends primarily on consistently passing over the barrier at minimum height.

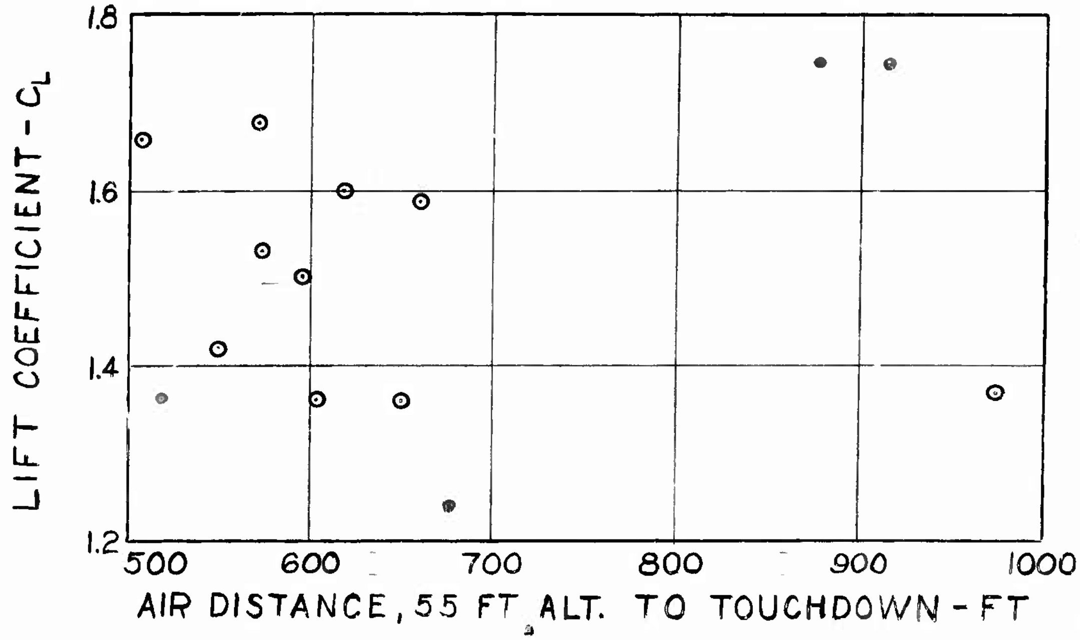

Figure 5

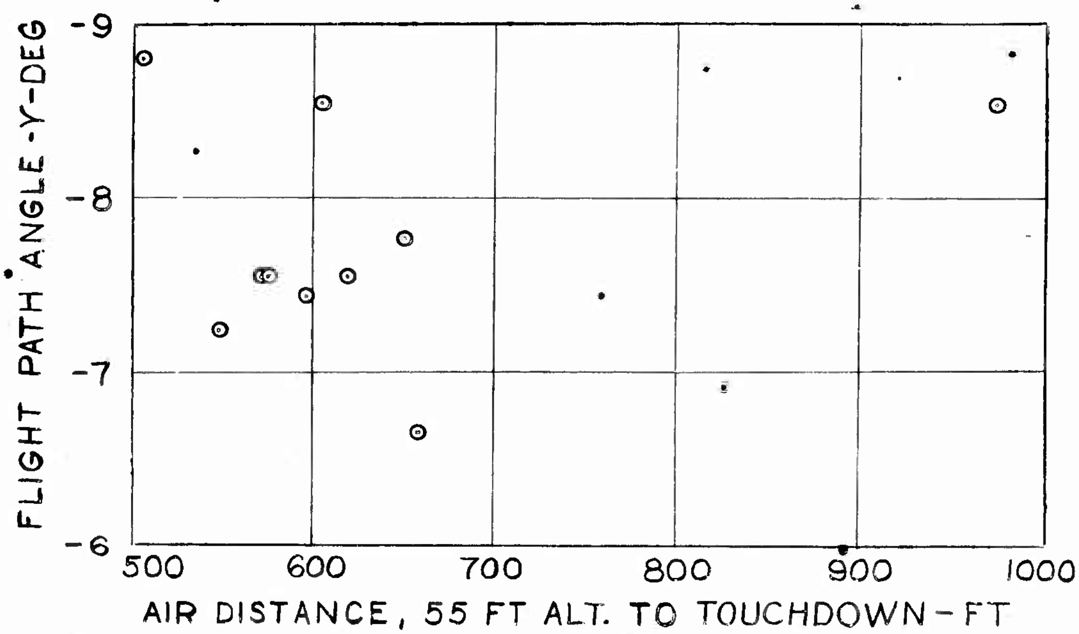

Figure 6

In summation, the pilot could adquately sense path errors during the approach to the barrier but the airplane afforded him little capability to do anything about these errors. While the maximum descent angle of this airplane could readily be realized, the range of available path angles did not permit accurate control of height at the barrier, and variations in height at the barrier had the greatest influence on landing distance. No other factor or factors in combination produced a significant effect on landing distance.

2. Factors in the flare maneuver

The salient impression resulting from analysis of the factors involved in the flare maneuver was that none of the factors or combinations thereof caused any appreciable effect on total air distance. No trend was evident with regard to lift coefficient at the beginning or end of the flare, height at which the flare commenced, total elevator deflection used, rate of elevator application, pitch attitude at touchdown, or radius of flare. Certain characteristics were observed, however:

a. The average elapsed time from the aircraft passing through a 55 foot altitude to the touchdown point was 5.509 seconds with the maximum and minimum times equal to 5.954 and 4.601 seconds respectively. The variation of less than one second demonstrates the repeatability of the flare maneuver and the insignificance of variation in parameters. The height at which the flare commenced varied from 46 feet to 10 feet, the time required for complete elevator action varied from 2 to 5 seconds, and the velocity at touchdown varied from 89 to 105 ft/sec.

b. The short time available after passing the barrier (5.5 seconds average until touchdown) in comparison to the transient response of the airplane to go-around action (3 seconds to reach level flight) forces the pilot to decide whether or not to complete the landing upon or prior to reaching the barrier.

c. It is desirable to cause the airplane to touchdown at the end of the flare without "float", i.e., as soon as possible after the landing gear geometry is compatible with striking the ground and sink rate has been reduced to an acceptable level. The only method of doing this in the U-1A was to time the elevator action and to keep the airspeed low enough so as to "run out of energy" as soon as the pitch attitude reached three-point. This required an elevator action as shown in Fig. 7. The plots of elevator deflection versus time for all landings were nearly identical, differing only in the early portion of elevator application.

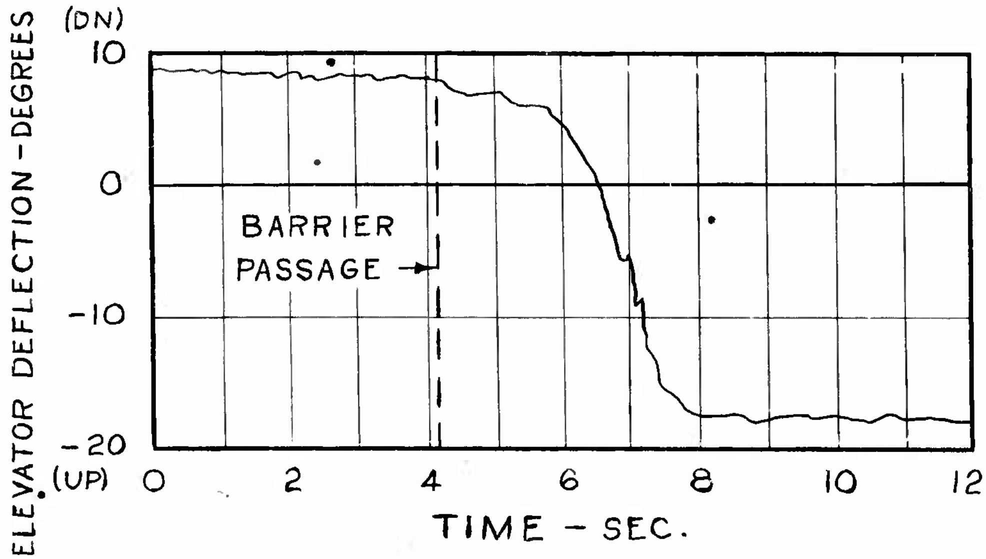

Figure 7

While the technique of holding airspeed low and timing the elevator action produced repeatable landings, a certain amount of anxiety accompanied this technique since it was a one-shot method and no recovery was possible if the elevator was mistimed.

The summary results of all factors are best seen in a tabulation of landing performance:

The computed minimum air distance for the U-1A is as follows:

$C_{L_{approach}}$	1.75
$C_{L_{max}}$	2.00
α approach	-7.50^{o}

R, radius of flare, 2140 ft.

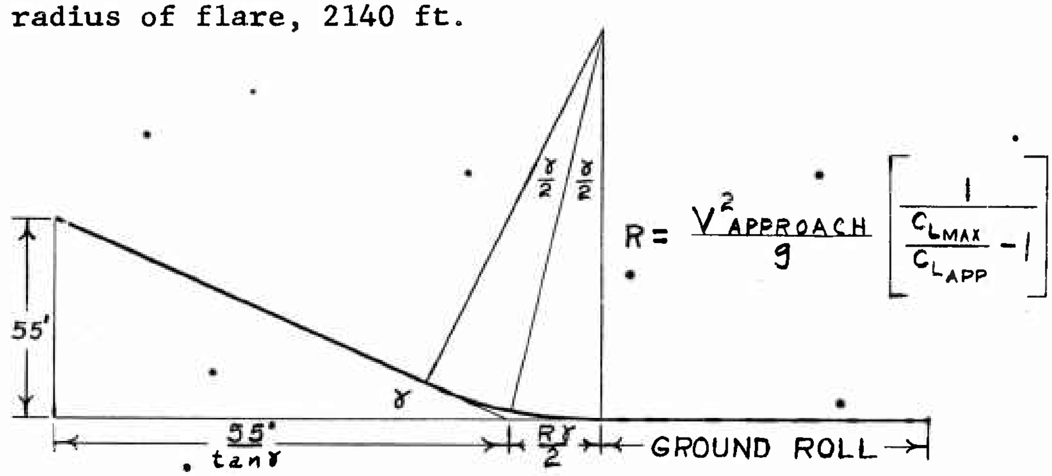

Figure 8 - Landing Path Geometry

Air distance $= \frac{55 \text{ ft}}{\tan \alpha} + \frac{R\alpha}{2} = 417 \text{ ft} + 140 \text{ ft} = 557 \text{ ft}$

Ground roll, average values from previous flight testing = 400 ft

Total minimum landing distance, M, = 957 ft

Landing Test Results

Average landing distance from 50 ft barrier <u>1249</u> ft

X_a = actual average landing distance less computed minimum landing distance <u>292</u> ft

X_a/M 31%

Longest landing distance from 50 ft barrier <u>1800</u> ft

X_w = actual longest landing distance less computed minimum landing distance <u>843</u> ft

X_w/M 88%

Average landing distance from 55 ft altitude <u>1027</u> ft

X_a = actual average landing distance less computed minimum landing distance <u>70</u> ft

X_a/M 7%

Longest landing distance from 55 ft altitude <u>1373</u> ft

X_w = actual longest landing distance less computed minimum landing distance <u>416</u> ft

X_w/M 43%

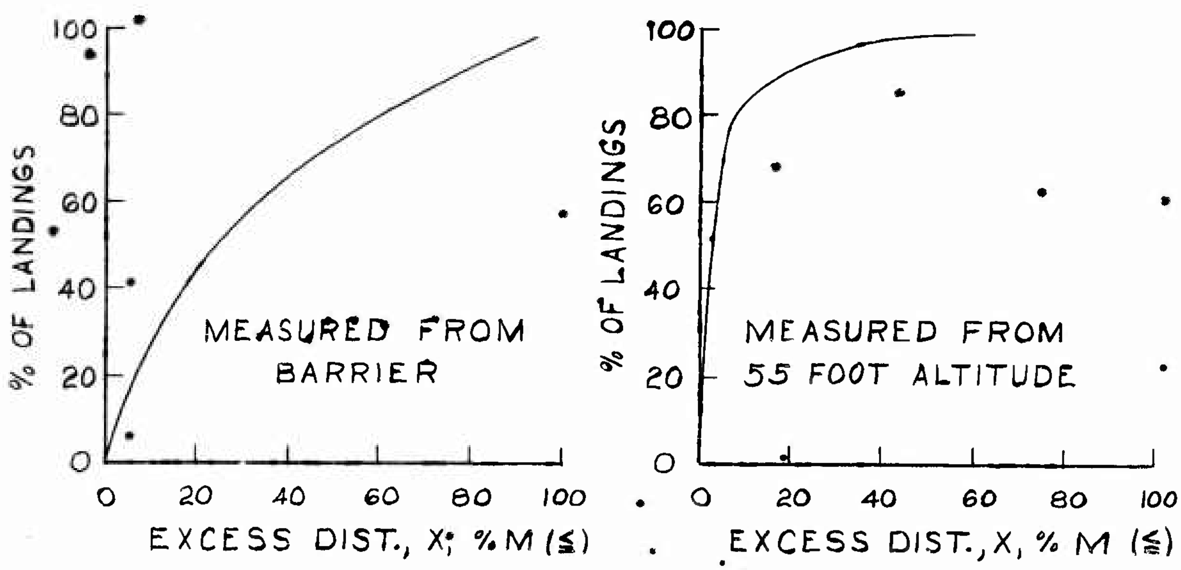

Figure 9 - Distribution of Landings

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CONCLUSIONS

1. The actual maximum air landing distance for the DeHavilland U-1A exceeded the computed minimum distance by 88% (i.e., X_w = 88%M) while the average excess was 31% (X_a = 31%M).

2. The single significant factor influencing landing distance was height at the barrier. When the effects of this variable were removed, X_w became 42% and X_a became 7%M.

3. Other than height at the barrier, the pilot was consistently capable of achieving minimum distance landing, independent of variations in lift coefficient, flare techniques, or any other variable.

4. In the DeHavilland U-1A the decision to land is made at least upon reaching or prior to reaching the barrier. For any improved STOL airplane, the decision will be made probably even earlier.

5. The pilot lacks a method of causing the airplane to touchdown upon completion of the flare. Using airplane stall to accomplish this is a committed maneuver, requires precision control of airspeed, and implies some risk. Any method of "dumping" wing lift such as quick retracting flaps or a tricycle landing gear could better provide this control.

6. The pilot can adequately sense errors to the minimum distance approach path, but in the case of the U-1A the path angle cannot be changed by more than $\pm 1/2$ degree. This amount is insufficient to provide consistency in landing in the minimum distance. The parameters of an airplane must provide path angle changes of $\pm 50\%$ of the desired average descent angle to accomplsih minimum landing distances consistently.

REFERENCES

1. "Evaluation of the Performance, Stability and Control of the Helio Courier Airplane," By A.J. Craig, U.S. Army Transportation Research and Engineering Command, Contract DA 44-177-TC-369, University of Wichita Engineering Research Report No. 264, February 1957.

2. "Evaluation of the Performance, Stability and Control of the DeHavilland U-1A "Otter" Airplane," by Warren L. Yarnell, U.S. Army Transportation Research and Engineering Command, Contract DA 44-177-TC-356, University of Wichita Engineering Research Report No. 304-11, December 1958.

APPENDIX A

U-1A Specifications

PHYSICAL GEOMETRY OF THE TEST AIRCRAFT

Weights

Gross weight	8000 lbs.
Empty weight	Approx. 4840 lbs.

Power Plant

Pratt & Whitney R-1340, Model S3h1-G	
Take-off HP @ 2250 rpm	600
Normal Rated HP @ 2200 rpm	550

Carburetor - Stromberg, float type

Propeller - Hamilton Standard Hydramatic
11 foot diameter, 3 blade, Model 23D40

Wing

Area (including ailerons, flaps and fuselage section)	375 sq.ft.
Span	58 ft.
Chord	78 in.
Taper	0
Aspect Ratio	8.97
Section	Mean Line-64-A Thickness-NACA 0016 Modified
Sweep	0°
Twist	0°
Flap Area	98.0 sq.ft.
Flap Span	49.7 ft.
Flap Chord, % MAC	
Out Board	15%
In Board	30%
Aileron Area, aft of hinge line	26.3 sq.ft.
Aileron Span	26.9 ft.
Aileron Chord, % MAC	15%
Wing Incidence	2-1/2°
Dihedral	2°

Horizontal Tail

Total Area	84 sq.ft.
Elevator Area, including balance area	46.0 sq.ft.
Span	21 ft. 2 in.
Chord	
Root	60 in.
Tip	36.5 in.
Incidence (from datum)	0°
Volume Coefficient	0.89

Vertical Tail

Total Area	60.2 sq.ft.
Rudder Area, including balance area	27.0 sq.ft.
Effective Aspect Ratio	2.0
Volume Coefficient	0.074

Fuselage

Overall Maximum Length	41 ft.10 in.
Cabin Volume	356 cu.ft.
Cabin Width (floor level)	52.4 in.
Cabin Height	59 in.
Overall Airplane Height (3 point)	12 ft.17 in.
Overall Airplane Height (level)	17 ft. 4 in.

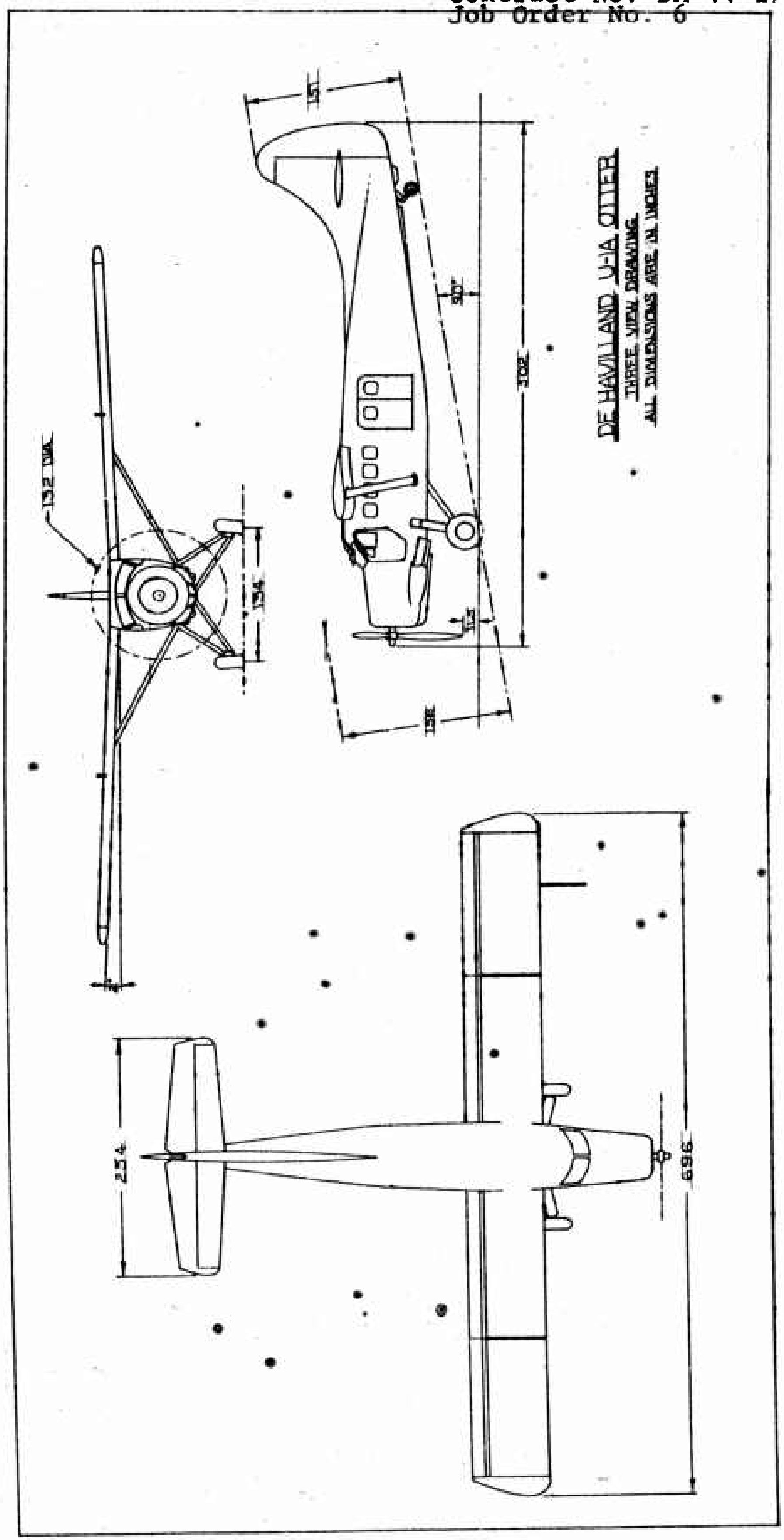
DE HAVILLAND U-1A OTTER
THREE VIEW DRAWING
ALL DIMENSIONS ARE IN INCHES
132 DIA
134
302
254
696

Figure 9

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APPENDIX B

Instrumentation

Instrumentation

The bulk of flight test instrumentation used in this program was comprised of equipment used in previous flight testing performed at the University of Wichita under U.S. Army contracts DA 44-177-TC-369 and DA 44-177-TC-356. A detailed description of this equipment is contained in Ref. 1 and 2.

Certain portions of the instrumentation were modified to provide more detailed measurement of transient phenomena than was possible with the previous arrangement. Data had originally been recorded on a photopanel. To provide both digital and analog information on variables which were of primary interest in this investigation, the photopanel was supplemented with a twelve channel recording oscillograph. Strain gage accelerometers were installed to measure normal and chordwise components of acceleration. A rate gyro was installed to record pitch attitude rate on the oscillograph. Finally, the transducers measuring angle of attack, airspeed, and elevator deflection were altered to provide a frequency response adequate to define these variables during transient maneuvers.

Both the photopanel and the recording oscillograph were synchronized to provide time correlation with a Fairchild Flight Analyzer camera. Since the emphasis of the program was on landing performance, the Fairchild camera served as the master reference and the other two instruments were correlated with it.

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APPENDIX C

Test Procedure

Test Procedure

Upon completion of installation and ground calibration of instrumentation, the aircraft was ballasted to a gross weight of 8000 lbs. at an intermediate center of gravity location of 29% mean aerodynamic chord. This loading is mid-way between forward and aft center of gravity limits and is typical of an operational configuration. The airspeed system was flight calibrated and stall speed tests and glide sawtooth polars were performed for comparison with data previously obtained. Stall speeds checked within 2 mph of earlier results and differences in glide polar data were within experimental error.

For the testing involved with measuring landing performance over a barrier, a physical 50 foot barrier consisting of chord stretched between two poles was used. Bright colored cloth tassels were hung from the chord to make the barrier more visible to the pilot while bullseye targets were placed at the top of the barrier poles to make them visible in the Fairchild camera data photographs. The pilot, utilizing the techniques described in the introduction section of this report, attempted to pass the airplane over the barrier and come to a stop as soon as possible. A sample Fairchild camera photograph is shown in Fig. 10.

Other tests were performed to simulate landing flares at altitude. From these tests it was desired to measure the transient response of flight path, angle of attack, and pitch attitude to control action out of ground effect for comparison with the same responses in ground effect. No success in detecting any changes in stability derivatives or aerodynamic coefficients had been achieved at the end of the program.

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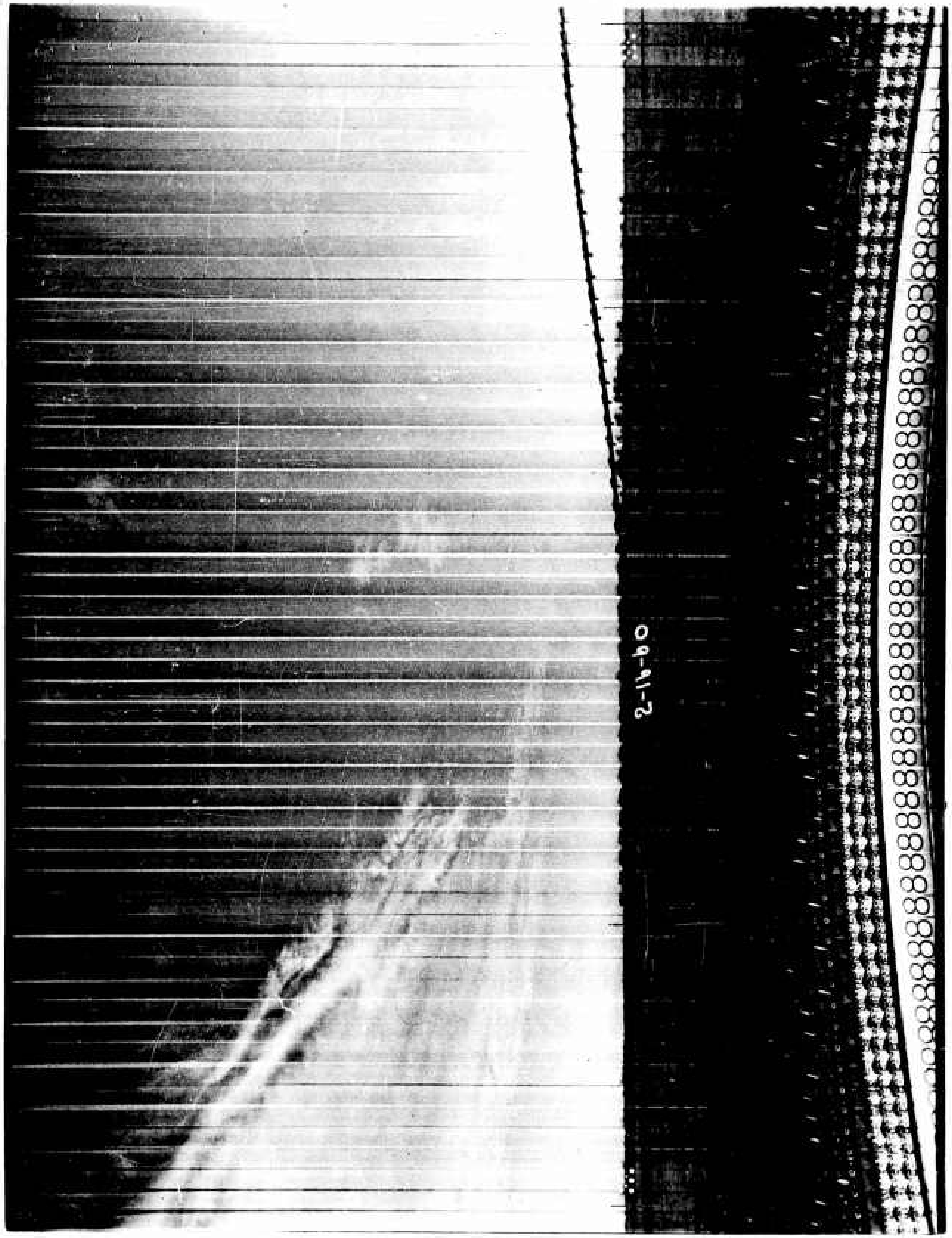

Figure 10

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APPENDIX D

Data Reduction

Data Reduction

Landing distances as measured on the Fairchild camera photographs were corrected for variations in gross weight of the airplane in accordance with AGARD techniques prior to comparison of performance. Atmospheric conditions were nearly those of a standard sea-level day so that no altitude corrections were required. Instrument errors were removed from the data obtained with the photopanel and the recording oscillograph prior to plotting time histories of the variables measured. No other corrections were applied to the recorded data.

APPENDIX E

Tabulated Data

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TABULATED DATA

		LANDING NO.									
		1	2	3	4	5	6	7	8	9	10
(1)	Air distance, barrier to touchdown - ft -	1055	1125	703	703	1400	798	616	680	870	537
(2)	Air distance, 55 ft. altitude to touchdown - ft -	650	973	548	603	570	596	618	658	573	505
(3)	Altitude at barrier - ft -	107	22	20	18	98	30	4	8	43	7
(4)	Lift coefficient @ barrier	1.36	1.37	1.42	1.36	1.68	1.500	1.60	1.59	1.53	1.66
(5)	Velocity @ barrier, - ft/sec	114	114	112	114	102	108	104	105	107	102
(6)	Path Angle @ barrier - degrees	7.75	8.55	7.25	8.55	7.55	7.45	7.55	6.65	7.55	8.8
(7)	Time from 55 ft. altitude to touchdown, - seconds	5.87	8.87	5.35	5.34	5.37	5.59	5.72	5.95	5.43	4.60
(8)	Altitude @ start of flare - ft	21	47	33	34	27	21	25	21	10	17
(9)	Velocity @ start of flare - ft/sec	112	114	111	112	100	105	105	105	101	105
(10)	Radius of flare - ft	2870	3310	3250	2990	2560	2500	2800	3270	1120	1540
(11)	Velocity at touchdown - ft/sec	106	104	103	102	96	94	90	91	95	92
(12)	Attitude @ touchdown, level or 3-point	level	3-pt	level	level	3-pt	3-pt	3-pt	3-pt	3-pt	3-pt
(13)	Ground roll, ft	N.A.	344	727	538	490	338	300	340	393	300

NOTE:
1. All distances corrected for gross weight variations.
2. On landing #2, the aircraft "floated" for 300 ft. in a three-point attitude, approximately 1-1/2 ft. above runway.
3. Wind conditions throughout the landings involved light to moderate turbulence with velocities of 5-10 knots at a right quartering headwind.

AD Accession No.__________

University of Wichita, Department of Engineering Research, Wichita, Kansas
ACHIEVING CONSISTENCY IN MAXIMUM PERFORMANCE STOL LANDINGS - A.J. Craig

Report TREC 61-41, January 1961, 37 pp, illus., tables and graphs (Contract DA 44-177-TC-356) DA Proj. 9R38-11-009-02, Unclassified Report.

SUMMARY - Factors influencing the achievement of minimum distance landings over a barrier were investigated to determine what might be done to provide consistency in landing in a computed minimum distance. It was found that the pilot regularly extracted the maximum aerodynamic performance of the airplane, but that limitations accompanying maximum aerodynamic performance prevented consistently short landings. The primary limitation was the inability to flatten or steepen the descent path during the approach to the barrier.

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1. Aircraft - flying qualities
2. Contract DA 44-177-TC-356
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